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Horizontal and Upward Tau Airshowers in Valleys from Mountains and Space: Discovering UHE Neutrinos and New physics

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Abstract. Upward and horizontal τ Air-showers emerging from the Earth crust or mountain chains are the most powerful signals of Ultra High Energy UHE neutrinos ν_τ, $\bar{\nu}_\tau$ and $\bar{\nu}_e$ at PeV and higher energy. The multiplicity in τ Air-showers secondary particles, $N_{opt} \simeq 10^{12}(E_\tau/PeV)$, $N_\gamma(< E_\gamma >\sim 10\,MeV) \simeq 10^8(E_\tau/PeV)$, $N_{e^-e^+} \simeq 2 \cdot 10^7(E_\tau/PeV)$, $N_\mu \simeq 3 \cdot 10^5(E_\tau/PeV)^{0.85}$ make easy its discover. UHE ν_τ , ν_τ following Super Kamiokande evidence of neutrino flavor mixing, ($\nu_\mu \leftrightarrow \nu_\tau$), should be as abundant as ν_μ, $\bar{\nu}_\mu$. Also anti-neutrino electrons, $\bar{\nu}_e$, near the Glashow W resonance peak, $E_{\bar{\nu}_e} = M_W^2/2m_e \simeq 6.3 \cdot 10^{15}\,eV$ may generate τ Air-showers . Upward UHE $\nu_\tau - N$ interaction on Earth crust at horizontal edge and from below, their consequent upward UHE τ air-showers beaming toward high mountains, air-planes, ballons and satellites should flash γ, μ, X and Cherenkov lights toward detectors. Such upward τ air-shower may already hit nearby satellite GRO gamma detectors flashing them by short, hard, diluted $\gamma-$burst at the edge of BATSE threshold. The τ air-shower may test the UHE neutrino interactions leading to additional fine-tuned test of New TeV Physics both in Mountain Valleys and in Upward showers.

1 Introduction: UHE astrophysical neutrino detection by Vertical and Horizontal detectors

Ultra High Energy UHE neutrino of astrophysical origin above tens TeV might overcome the nearby noisy signals of secondary atmospheric neutrinos. Present and future underground cubic Kilometer detectors are looking for the muon penetrating tracks to associate spatially to remarkable persistent astrophysical source (AGN,SN,Microquasar) or to rarest GRB event. Downward muons, secondary of air-showers, are dominating and polluting the down-vertical signals; upward muons by UHE neutrinos ν_μ, $\bar{\nu}_\mu$ at low energies (below TeV) are again polluted by atmospheric neutrinos; higher energy neutrinos ν_μ, $\bar{\nu}_\mu$ above $10^{13}eV$ may better probe the astrophysical neutrino, but upward ones unfortunately are more and more suppressed by the Earth opacity. Upward Tau neutrinos, to be discussed later, are less opaque, but at $10^{13}eV - 10^{14}eV$, they leave shorter tracks and are less detectable. Therefore the best strategy in underground detectors should consider Horizontal Underground Arrays. For this reason we criticized present vertical tower-like underground array detectors and we strongly suggest to consider the construction of wide disk-like arrays finalized to Horizontal UHE astrophysical neutrinos. At the depth h the horizontal distances $d(\theta) =$:

$$|(R_\oplus - h) \cdot \sin\theta \pm \sqrt{(R_\oplus - h)^2 \cdot \sin^2\theta + (2hR_\oplus - h^2)}| \quad (1)$$

$$d(\theta = 0) = \sqrt{(2R_\oplus \cdot h)} \simeq 110\sqrt{\frac{h}{Km}} \cdot Km \quad (2)$$

Such distances are not too deep to suppress UHE neutrinos even at GZK $10^{10}eV$ energies. Therefore nearly horizontal UHE muon traces are cleaner signature of UHE neutrino astrophysics.

Moreover UHE ν_τ and $\bar{\nu_\tau}$ may be converted and they may reach us from high energy galactic sources, as pulsars, Supernova remnants or galactic micro-quasars and SGRs , as well as from powerful extra-galactic AGNs, QSRs or GRBs, even at highest (GZK) energy because of the large galactic (Kpcs) and extreme cosmic (Mpcs) distances:

$$L_{\nu_\mu - \nu_\tau} = 4 \cdot 10^{-3}\,pc \left(\frac{E_\nu}{10^{16}\,eV}\right) \cdot \left(\frac{\Delta m_{ij}^2}{(10^{-2}\,eV)^2}\right)^{-1} \quad (3)$$

2 Tau Air-shower detecting UHE neutrinos

These Tau air-showers are detectable in deep valleys or on front of large mountain chains like Alps , Rocky Mountains,Grand Canyons,Himalaya and Ande; the latter chain is near present AUGER project (Fargion et al.) (1999) and could offer an

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ideal lateral source of nearly horizontal air-shower. A natural valley to locate the future Array Telescope able to trace such EeV Tau Air-shower fluorescent lights is the Death Valley in USA: its size and depth may capture EeV events. The mountain chains and the air act as a fine tuning multi filter detector: as a screen of undesirable rare but noisy horizontal $(> 70^o)$ UHECR showers (mainly electro-magnetic ones, Cherenkov photons, X,gamma and muons); very rare unexplicable hadronic horizontal interaction by UHE secondary pion from a mountain may occur. The Mountain acts as a dense calorimeter for UHE$\bar{\nu_\tau}$ nuclear events (three order of magnitude denser than air slant depth on the horizons); as a distance meter target correlating τ birth place and its horizontal air-shower opening origination with the cosmic ray energy density; as a characteristic anti neutrino $\bar{\nu_e}$ detector by the extreme resonant cross section $\bar{\nu_e} - e$ at Glashow peak and the consequent fine-tuned energy (few PeV) shower events; as a very unique source of dense muon bundles from a mountain by main tau hadronic air-showering.

The vertical up-ward tau air-showers (by small arrival nadir angle) occur preferentially at low energies nearly transparent to the Earth ($E_\nu \sim 10^{15} - 10^{16}$ eV). The oblique τ air showers (whose arrival directions have large nadir angle), may be related also to higher energy ν_τ, or $\bar{\nu_\tau}$ nuclear interactions ($E_{\bar{\nu_\tau}} \geq 10^{17} - 10^{19}$ eV). Indeed these horizontal - upward UHE ν_τ cross a smaller fraction of the Earth volume and consequently they suffer less absorption toward the horizon. Moreover the consequent ultra-relativistic ($E_{\bar{\nu_\tau}} \geq 10^{17} - 10^{19}$ eV) tau may travel in atmosphere for few or even hundred Kms with no absorption before the decay to the detector located at few Kms distance. On the contrary the horizontal gamma, electron pairs and muon showers by primary (down-ward nearly horizontal) UHECR proton are severely suppressed ($\geq 10^{-3}$) after crossing ($\geq 2 \cdot 10^3\, g \cdot cm^{-2}$) slant depth, or equivalent at one atmosphere, ($\geq 16 Kms$) of horizontal atmosphere target.

These huge horizontal or upward air-shower signals being at least million to billion times more abundant than the original and unique UHE τ or UHE μ track in underground Km cube detectors are much easier to be discovered with no ambiguity. These high energy PeVs tau air-shower are mainly of astrophysical nature. Indeed they cannot even be produced by PeV atmospheric neutrino secondaries born in atmospheric muon flavor and oscillating in tau state, because their high PeV energy and their consequent large oscillation lengths are much (hundred times) longer than the Earth diameter.

Present τ air shower is analogous to the well-known Learned and Pakwasa (1995) "double bang" in underground neutrino detectors. The novelty of the present "one bang in" (the rock, the mountain, the Earth) - "one bang out" (the air) lays in the self-triggered explosive nature of τ decay in flight and its consequent huge amplified air shower signal at a characteristic few Kms distance.

3 The UHE $\bar{\nu}_e$, ν_τ, $\bar{\nu}_\tau$ and τ interaction lenghts

Moreover the expected ν_τ signals, by their secondary tau tracks at highest cosmic ray energy window $1.7 \cdot 10^{21}\, eV > E_\tau > 1.6 \cdot 10^{17}\, eV$, must exceed the corresponding ν_μ (or muonic) ones, making UHE ν_τ above 0.1 EeV the most probable UHE signal. Indeed, the Lorentz-boosted tau range length grows (linearly) above muon range, for $E_\tau \geq 1.6 \cdot 10^8 GeV$; (see Fig (1) eq.5): the tau track reaches its maxima extension, bounded not by bremsstrahlung radiation length nor by pair production (eq. 4), but by growing nuclear (mainly photonuclear) and mainly, later, by electro-weak interactions (eq. 6), $R_{\tau_{\max}} \simeq 191\ Km$, at energy $E_\tau \simeq 3.8 \cdot 10^9\ GeV$ in water.

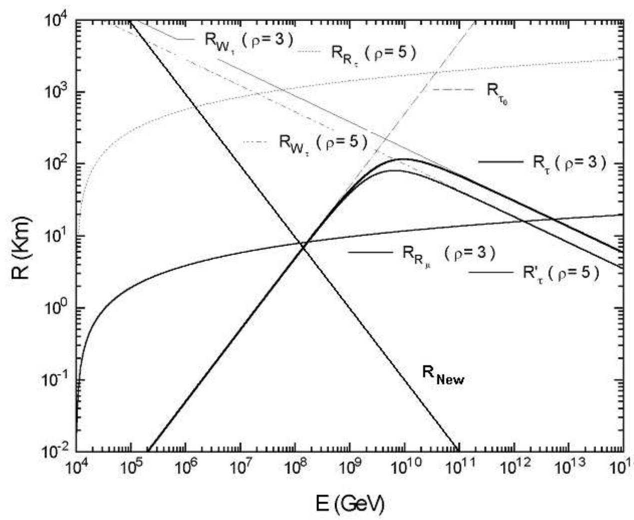

Fig. 1. The tau ranges as a function of the tau energy respectively for tau lifetime (dashed line) R_{τ_o}, for over-estimated tau radiation range R_{R_τ}, (short dashed line above) and tau electro-weak interaction range R_{W_τ}, for two densities $\rho = 3$, $\rho = 5$, ρ_r (long dashed lines, continuous) and their combined range R_τ. Below the corresponding radiation range R_μ for muons (dotted line). Finally the solid line R_{New} shows the interaction length due to New physics (extra dimension Gravity) at TeV for a matter density of rock $\rho = 3$.

$$R_{R_\tau} \cong 1033\, Km\, \frac{5}{\rho_r} \left\{ 1 + \frac{\ln\left[\left(\frac{E_\tau}{10^8 GeV}\right)\left(\frac{E_\tau^{\min}}{10^4 GeV}\right)^{-1}\right]}{(\ln 10^4)} \right\} \quad (4)$$

$$R_{\tau_o} = c\tau_\tau\gamma_\tau = 4.902\,\mathrm{Km}\,\left(\frac{E_\tau}{10^8\,\mathrm{GeV}}\right) \quad (5)$$

$$R_{W_\tau} = \frac{1}{\sigma N_A \rho_r} \simeq \frac{2.6 \cdot 10^3\,\mathrm{Km}}{\rho_r}\,\left(\frac{E_\tau}{10^8\,\mathrm{GeV}}\right)^{-0.363} \quad (6)$$

$$R_{New} = \frac{1}{\sigma_{New} N_A \rho_r} \simeq \left(\frac{E_\tau}{10^8\mathrm{GeV}}\right)^{-1} \left(\frac{E_{New}^{TeV}}{10^3\mathrm{GeV}}\right)^{-4} \frac{Km}{\rho_r} \quad (7)$$

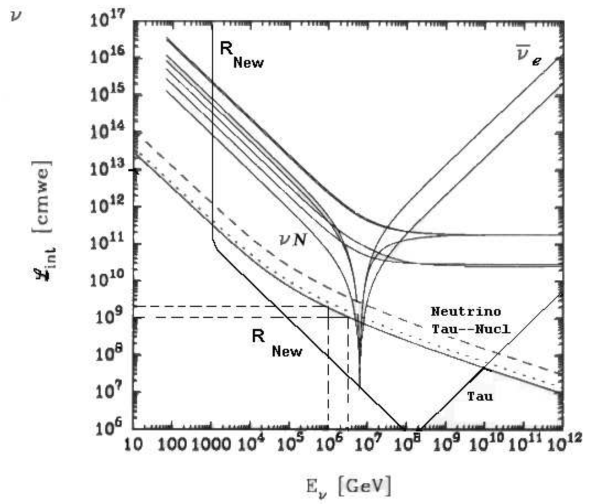

Fig. 2. The Gandhi et all (1998) UHE neutrino ranges as a function of UHE neutrino energy in Earth with overlapping the resonant $\bar{\nu}_e e$, $\nu_\tau N$ interactions; below in the corner the UHE τ range, as in Fig 1, at the same energies in matter (water). Finally the solid line R_{New} shows the interaction length due to New physics (extra dimension Gravity) at TeV for a matter density of rock $\rho = 3$

It should be noticed that the radiative τ length estimated above has been considered for bremsstrahlung radiation length only. Pair production energy loss is more restrictive in the final R_{R_τ} length (by an approximate factor $\frac{m_\tau}{m_\mu}$) as well as the growing photo-nuclear interactions at highest (tens EeV) energies. However the very dominant electro-weak interactions at these energies are already suppressing the τ growth and the combined interaction length are slightly less, but almost comparable to the one shown in figure above.

At the peak maxima the tau range is nearly 10-20 times longer than the corresponding muon range (at the same energy) implying, for comparable fluxes, a ratio 10 times larger in ν_τ over ν_μ detection probability. This dominance, may lead to a few rare spectacular event a year (if flavor mixing occurs) preferentially in horizontal plane in new concept underground Km^3 detectors. The Earth opacity at those UHE regimes at large nadir angles (nearly horizontal, few degree upward direction) is exponentially different for UHE muons respect to tau above EeV : the ratio among UHE ν_τ over ν_μ tens Kms signals is exponentially high $> \exp(10)$.

Therefore UHE Tau $E_\tau \geq\ 10^5 GeV - 5\cdot 10^7 GeV$ air-shower in front of high mountains chains will be easily induce peculiar horizontal UHE τ (Fargion, Aiello, Conversano 1999). Energies above will be probably missed. An hybrid detector (gamma/optical air-shower array) would get precise signal and arrival direction. Because of the different neutrino interactions with energy it will be possible to estimate, by stereoscopic, directional and time structure signature, the spatial air-shower origination in air, the primary tau distance decay from the mountain (tens or a hundred of meters for fine tuned PeVs UHE $\bar{\nu}_e$ and meters up to few Kms for UHE ν_τ,$\bar{\nu}_\tau$ at wider energy window $E_\tau \geq\ 10^5 GeV - 5\cdot 10^7 GeV$. Additional energy calibration may be derived sampling shower intensities.
Hundreds of array (scintillator,Cherenkov) detectors in deep wide valley horizontally oriented would be necessary to get tens τ air–showers events a year; the induced $\bar{\nu}_e e \rightarrow \tau$ air shower even in absence of $\nu_\mu \leftrightarrow \nu_\tau$ oscillation should be well identified and detectable. More copious ($>\ 5$ times more) events by PeV up to tens PeV charged current $\nu_\tau N$ interaction occur following Super Kamiokande flavor mixing discover. It will be also possible to observe UHE ν_τ, by the upward tau air-shower arriving from tens or hundred Kilometers away (near horizontal edges) from high mountains, high balloon and satellites; such UHE tau created within a wide (tens thousands to millions square km^2 wide and hundred meter UHE Tau depth in Earth crust) target would discover only UHE ν_τ,$\bar{\nu}_\tau$ neutrinos at PeV up to EeV energies and above, just within the mysterious GZK frontiers. From the same highest mountains, balloons and near orbit satellite, looking more downward toward the Earth it is possible to discover more frequent but lower energetic astrophysical $\simeq 10^{14} \div 10^{16}\ eV$ neutrinos (by consequent Tau Air-showers) being nearly transparent to the Earth volume;(See Fig.2). The UHE neutrinos $\bar{\nu_e}$,ν_μ $\bar{\nu}_\mu$ are default and expected UHECR ($\gtrsim 10^{16}$ eV) secondary products near AGN or micro-quasars by common photo-pion decay relics by optical photons nearby the source (PSRs, AGNs) ($p+\gamma \rightarrow n+\pi^+, \pi^+ \rightarrow \mu^+\nu_\mu, \mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$), or by proton proton scattering in galactic interstellar matter. The maximal observational distances from mountains, balloons or satellites, may reach $\sim$ 110 Km $(h/Km)^{\frac{1}{2}}$ toward the horizon, corresponding to a UHE τ energy $\sim\ 2 \cdot 10^{18}$ eV $(h/Km)^{\frac{1}{2}}$. Therefore we propose to consider such upward shower nearly horizontal detection to test the highest UHE ν energies at GZK cut off. The expected downward muon number of events $N_{ev}(\bar{\nu}_e e \rightarrow \bar{\nu}_\mu \mu)$ in the resonant energy range, in Km^3, was found to be $N_{ev} = 6$ a year. One expect a comparable number of reactions $(\bar{\nu}_e e \rightarrow \bar{\nu}_\tau \tau)$. However the presence of primordial ν_τ, $\bar{\nu_\tau}$ by flavor mixing and ν_τ, $\bar{\nu_\tau} N$ charged current interactions lead to a factor 5 larger rate, $N_{ev} = 29$ event/year. If one imagines a gamma/optical detector at 5 km far in front of a chain mountain (nominal size 10 km, height 1 km) one finds a τ air shower volume observable within a narrow beamed cone (Moliere radius $\sim$ 80 m / distance $\sim$ 5 Km): ($\Delta\theta \sim 1^o$, $\Delta\Omega \sim 2 \cdot 10^{-5}$) and an effective volume $V_{eff} \simeq 9 \cdot 10^{-5}$ Km^3 for each observational detector. Each single detector is comparable to roughly twice a Super Kamiokande detector. Following common AGN - SS91 model [The Gandhi et all,1998] with a flux at present AMANDA-Baikal bounds we foresee a total event rate of: (6) ($\bar{\nu_e}e$) + (29) ($\nu_\tau N$) = 35 UHE ν_τ event/year/Km^3. At energies above 3 PeV we may expect a total rate of N$_{ev}$ $\sim$ 158 event/year in this mountains valley and nearly 3.2 $\cdot 10^{-3}$ event/year for each m^2 size detector. In a first approximation, neglecting Earth opacity, it is possible to show that the Earth volume observable from the top of a mountain at height h, due to UHE τ at 3 PeV crossing from below, is approximately V $\approx 5 \cdot 10^4$ Km^3 $\left(\frac{h}{Km}\right)\left(\frac{E_\tau}{3\,PeV}\right)$. These upward shower would hit the top of the mountain. For the same τ air shower beaming ($\Delta\theta \sim 1^o$, $\Delta\Omega \sim 2 \cdot 10^{-5}$) we derive now an effective volume ~ 1 Km^3. Therefore a detector open at 2π angle on a top of a 2 Km height mountain may observe nearly an event every two month from below the Earth. The gamma signal above few MeV would be (depending on arrival nadir angle) between $3 \cdot 10^{-2}$ cm^{-2} (for small nadir angle) to 10^{-5} cm^{-2} at far distance within 3 PeV energies. A contemporaneous (microsecond) optical flash ($\gtrsim 300 \div 0.1\, cm^{-2}$) must occur. Keeping care of the Earth opacity, at large nadir angle ($\gtrsim 60^0$) where an average Earth density may be assumed ($< \rho > \sim 5$) the transmission probability and creation of upward UHE τ is approximately

$$P(\theta,\, E_\nu) = e^{\frac{-2R_{Earth}\cos\theta}{R_{\nu_\tau}(E_\nu)}}\,(1 - e^{-\frac{R_\tau(E_\tau)}{R_{\nu_\tau}(E_\nu)}})\,. \qquad (8)$$

This value, at PeV is within a fraction of a million($\theta \approx 60^0$) to a tenth of thousands ($\theta \approx 90^0$). The corresponding angular integral effective volume observable from a high mountain (or balloon) at height h (assuming a final target terrestrial density $\rho = 3$) is:

$$V_{eff} \approx 0.3\, Km^3 \left(\frac{\rho}{3}\right) \left(\frac{h}{Km}\right) e^{-\left(\frac{E}{3\,PeV}\right)} \left(\frac{E}{3\,PeV}\right)^{1.363} \quad (9)$$

A popular "blazar" neutrino flux model (like Berezinsky ones) normalized within a flat spectra(at a standard energy fluence$\simeq 2\,10^3 \frac{eV}{cm^2}$) is leading, above 3 PeV, to ~ 10 UHE ν_τ upward event/Km^3 year. Therefore we must expect an average upward effective event rate observed on a top of a mountain (h $\sim 2\,Km$) (Fig. 4):

$$N_{eff} \simeq 8\,\frac{\text{events}}{\text{year}} \left(\frac{\rho}{3}\right) \left(\frac{h}{2\,Km}\right) e^{-\left(\frac{E}{3\,PeV}\right)} \left(\frac{E}{3\,PeV}\right)^{1.363} \quad (10)$$

This rate is quite large and one expected τ air air-shower signal (gamma burst at energies $\gtrsim 10\, MeV$) should be $\phi_\gamma \simeq 10^{-4} \div 10^{-5}$ cm^{-2}, while the gamma flux at ($\sim 10^5\, eV$) or lower energies (from electron pair bremsstrahlung) may be two order of magnitude larger. The optical Cherenkov flux is large $\Phi_{opt} \approx 1$ cm^{-2}.

4 Upward τ Air Shower in Terrestrial Gamma Flash: evidences of UHE neutrinos?

The tau upward air showers born in a narrow energy window, 10^{15} eV $\lesssim E_\nu \lesssim 5 \cdot 10^{16}$ eV (Fig.3) may penetrate high altitude leaving rare beamed upward gamma shower bursts whose sharp ($\sim$ hundreds μsec because of the hundred kms high altitude shower distances) time structure and whose hard ($\gtrsim 10^5$eV) spectra may hit near terrestrial satellites. We claim (Fargion 2000) that such gamma upward events originated by tau air showers produce gamma bursts at the edge of GRO-BATSE sensitivity threshold. In particular we argue that very probably such upward gamma events have been already detected since April 1991 as serendipitous sharp ($\lesssim 10^{-3}$ sec) and hard ($\gtrsim 10^5$ eV) BATSE gamma triggers originated from the Earth and named consequently as Terrestrial Gamma Flashes (TGF). The visible Earth surface from a satellite, like BATSE, at height $h \sim 400$ Km and the consequent effective volume for UHE $\nu_\tau N$ PeVs interaction and τ air shower beamed within $\Delta\Omega \sim 2 \cdot 10^{-5} rad^2$ is: (note $< \rho > \simeq 1.6$ because 70 % of the Earth is covered by seas) $V_{eff} = V_{TOT} \Delta\Omega \simeq 60\, Km^3$. The effective volume and the event rate should be reduced, at large nadir angle ($\theta > 60^o$) by the atmosphere depth and opacity (for a given E_τ energy). Therefore the observable volume may be reduced approximately to within 15 Km^3 values and the expected UHE PeV event rate is

$$N_{ev} \sim 150 \cdot e^{-\left(\frac{E_\tau}{3\,PeV}\right)} \left(\frac{E_\tau}{3\,PeV}\right)^{1.363} \left(\frac{h}{400 Km}\right) \frac{\text{events}}{\text{year}} \quad (11)$$

The TGF signals would be mainly γ at flux 10^{-2} cm^{-2} at X hundred keV energies. The observed TGF rate is lower than the expected one (eq. 11) by nearly an order of magnitude, and this suggests higher E_ν energies (to overcome BATSE threshold) and consequently small additional probability suppression fitting the observed TGF events rate. We notice that among the 75 records only 47 are published by NASA in their details, while 28 TGF are still unpublished. Their data release is therefore urgent and critical. While Blue Jets might be in principle triggered by upward tau air showers in the atmosphere (a giant "Wilson" room) we believe they are not themselves source of TGF. In particular their observed characteristic propagation velocity ($\lesssim 100$ Km/s) from distances ~ 500 Km, disagree with short TGF millisecond timing and would favor a characteristic TGF time of few seconds. Moreover TGF data strongly dis-favor by its hard spectra the terrestrial Sprites connection. The correlations of these clustered TGFs directions toward well known and maximal powerful galactic and extra-galactic sources either at TeV, GeV-MeV, X band , recent first anisotropy discovered on UHECR at EeV by AGASA, (see Hayashida 1999,Fargion 2000), Milky Way Galactic Plane (Fig.3) and Center and well known EGRET sources, support and make suggestive the TGF identification as secondary gamma burst tail of UHE τ induced upward air shower. The present TGF-τ air-shower identification could not be produced by UHE $\bar{\nu}_e$ charged current resonant event at ($E_{\bar{\nu}_e} = M_W^2/2m_e = 6.3 \cdot 10^{15}$ eV), because of the severe Earth opacity for such resonant $\bar{\nu}_e$, and therefore it stand for the UHE $\nu_\tau \bar{\nu_\tau}$ existence. Consequently it gives support to the Superkamiokande evidences for $\nu_\mu \leftrightarrow \nu_\tau$ flavor mixing from far PSRs or AGNs sources toward the Earth. The same argument, as shown in Fig.2, imply a new upper bound on the possible New Physics Energy edge: It should not arise at threshold energies below ($E_{New} = 3TeV$). At the present the very probable $\nu_\tau \bar{\nu_\tau}$ source of TGFs and their probable partial galactic location infer a first lower bound on $\Delta_{m_{\nu_\mu \nu_\tau}}$ ($L < 4$ Kpc, $\Delta_{m_{\nu_\mu \nu_\tau}} > 10^{-8}$ eV^2) and it offers a first direct test of the same existence of the last evanescent (hardly observed only recently), fundamental neutral lepton particle: ν_τ and $\bar{\nu_\tau}$. The new physics interaction at TeV while forbid UHE signals in underground Km^3 detectors it will amplify the ν_τ signals by two order of magnitude making extremely fruit-full UHE ν_τ astrophysics in near future.

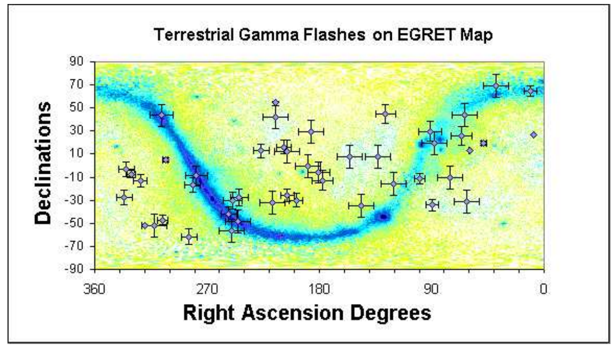

Fig. 3. The TGF on EGRET map. The TGF clustering toward the galactic center and known EGRET sources, their squeezing along the Galactic Plane make them probably of astrophysical nature.

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